US007694558B2

(12) **United States Patent**
Zaeper et al.

(10) **Patent No.: US 7,694,558 B2**
(45) **Date of Patent: Apr. 13, 2010**

(54) **DOWNHOLE WASHOUT DETECTION SYSTEM AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 8 days.

(21) Appl. No.: **12/028,913**

(22) Filed: **Feb. 11, 2008**

(65) **Prior Publication Data**

US 2009/0200079 A1 Aug. 13, 2009

(51) **Int. Cl.**
E21B 47/06 (2006.01)
E21B 21/08 (2006.01)

(52) **U.S. Cl.** **73/152.51**; 73/152.21; 73/152.22

(58) **Field of Classification Search** 73/152.43, 73/152.46, 152.51, 152.21, 152.22
See application file for complete search history.

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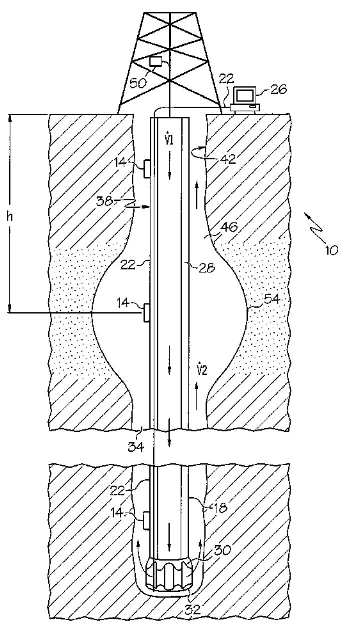
(57) **ABSTRACT**

Disclosed herein is a method of detecting a downhole washout. The method includes, positioning a plurality of sensors along a downhole drillstring, communicatively coupling the plurality of sensors to a processor, and analyzing data sensed by the plurality of sensors with the processor for relationships indicative of a washout.

21 Claims, 2 Drawing Sheets



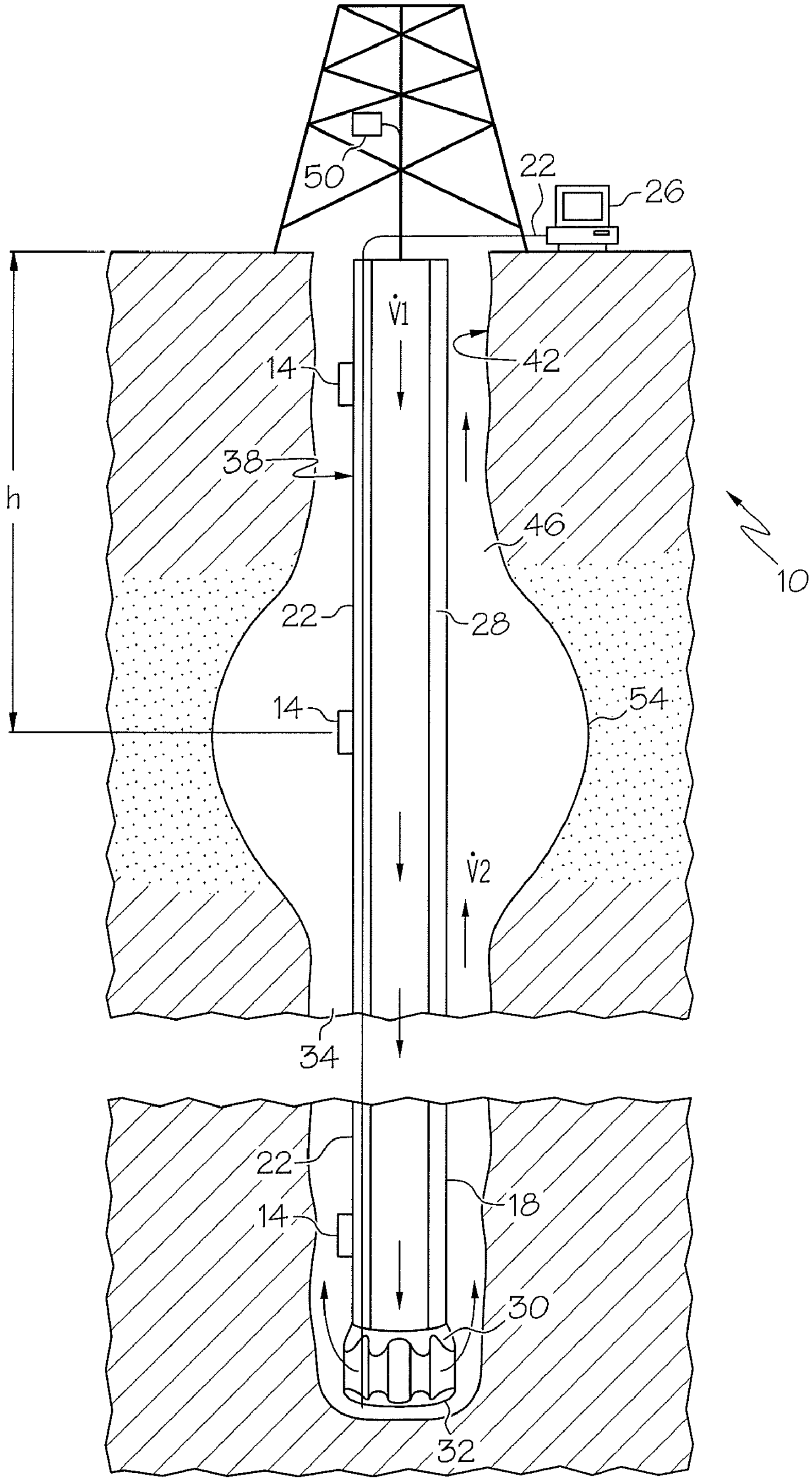
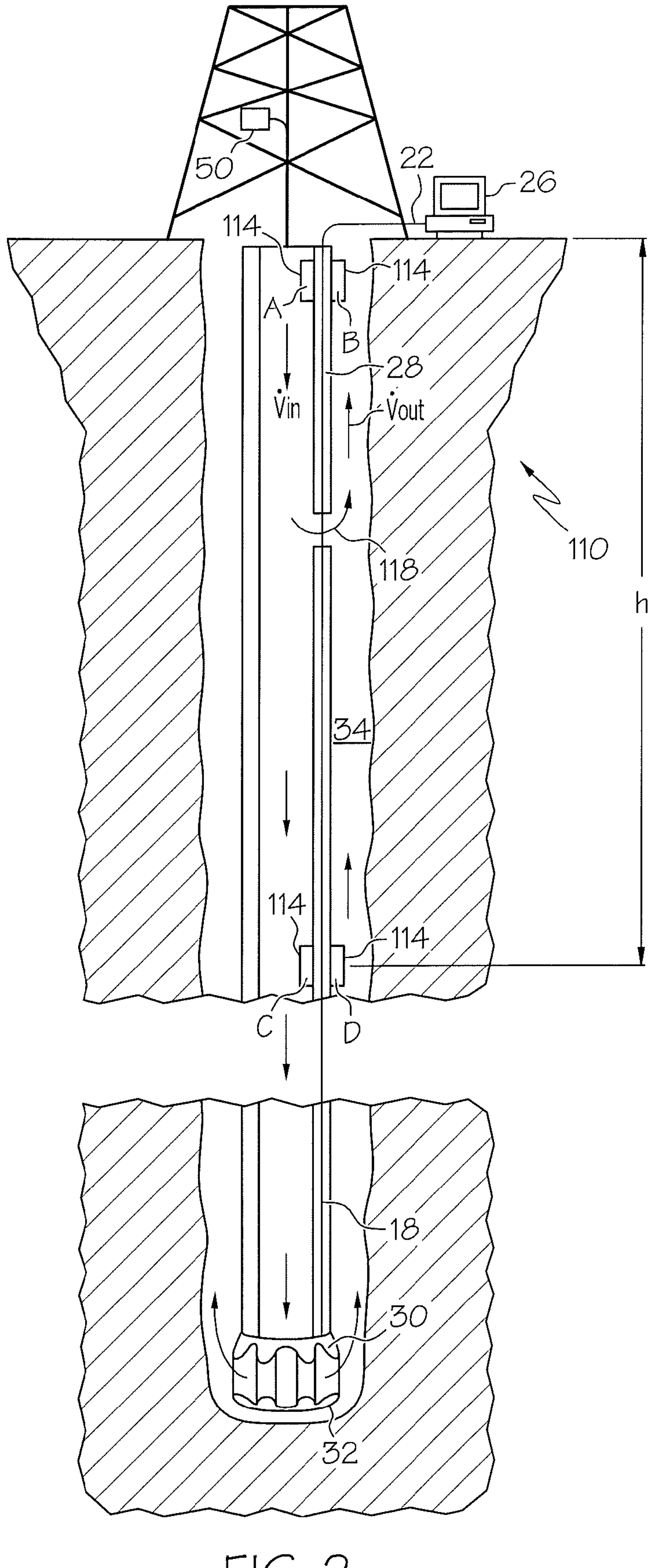


FIG. 1



50
22
26
114
114
A
B
28
$\dot{V}$in
$\dot{V}$out
110
118
h
34
114
114
C
D
18
30
32

FIG. 2

DOWNHOLE WASHOUT DETECTION SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

In the hydrocarbon recovery industry any loss of efficiency can be costly to a well operator. For example, a washout of a drill string or a formation while drilling can allow pumped mud to flow at rates other than the flow rates at which an operator believes they are flowing. Additionally, a washout can cause mud to flow to locations other than where the operator desires it to flow. Such conditions can cause issues during drilling due to a lack of mud flowing through the bit, for example. Methods and systems for detecting washouts as soon as they occur are therefore valuable to well operators.

BRIEF DESCRIPTION OF THE INVENTION

Disclosed herein is a method of detecting a downhole washout. The method includes, positioning a plurality of sensors along a downhole drillstring, communicatively coupling the plurality of sensors to a processor, and analyzing data sensed by the plurality of sensors with the processor for relationships indicative of a washout.

Further disclosed herein is a downhole drillstring washout detection system. The system includes, a plurality of sensors positioned downhole along a drillstring for measurement of at least one parameter therewith, a communication medium coupled to the plurality of sensors, and a processor coupled to the communication medium. The processor configured to receive data from at least the plurality of sensors, the processor further configured to determine relationships of sensed data indicative that a washout has occurred.

BRIEF DESCRIPTION OF THE DRAWINGS

The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. **1** depicts a washout detection system disclosed herein applied at a drillstring within a wellbore with a formation washout; and

FIG. **2** depicts a washout detection system disclosed herein applied to a drill string with a washout formed therein.

DETAILED DESCRIPTION OF THE INVENTION

A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

Referring to FIG. **1**, an embodiment of a washout detection system **10** disclosed herein is illustrated. The washout detection system **10** includes, a plurality of pressure sensors **14** positioned along a drillstring **18**, a communication medium **22** coupled to the plurality of pressure sensors **14**, and a processor **26** that is also coupled to the communication medium **22**. The communication medium **22** provides operable communication between the pressure sensors **14** and the processor **26** and can include a wired pipe **28**, for example, which permits high bandwidth data transmission there through. As such, the processor **26** can be located at surface, as disclosed herein or at some other location along the drillstring **18**, such as in a bottom hole assembly **30**, for example, while monitoring the pressure sensors **14**.

Positioning the pressure sensors **14** in an annulus **34** between an outer surface **38** of the drillstring **18** and an inner

surface **42** of a wellbore **46**, regardless of whether the wellbore **46** has a liner or not, allows for continuous monitoring of pressure at various wellbore depths within the annulus **34**. Such monitoring can be performed while drilling and while mud is being pumped downhole by a mud pump **50**, shown located at surface in this embodiment. Mud flowing back uphole through the annulus **34**, after flowing out through a bit **32**, will affect the pressure sensed by the pressure sensors **14**. Through the use of Bernoulli's Principle, which is based on conservation of energy, a relationship between pressure in the annulus **34** and area of the annulus **34** can be formed. Changes in flow area of the annulus **34** can, therefore, be determined and monitored for increases indicative of a formation washout **54** characterized by an increased flow area of the annulus **34**. Other mathematical models of the flow-pressure relation might be used in case of turbulent or mixed flow according to the local Reynold's number.

For a well without mud losses or fluid influx from the formation the mud volumetric flow rate, $\dot{V}_1$, from the mud pump **50** will be constant whether flowing down through the drillstring **18** or returning to surface through the annulus **34**, $\dot{V}_2$.

$$\dot{V}_1 = \dot{V}_2 \tag{1}$$

and since:

$$\dot{V}_1 = A_1 V_1 \tag{2}$$

$$\text{and } \dot{V}_2 = A_2 V_2 \tag{3}$$

then:

$$A_1 V_1 = A_2 V_2 \tag{4}$$

where:

A is the cross sectional flow area, and

V is the flow velocity.

Further, according to Bernoulli's Equation:

$$\frac{1}{2}\rho V^2 + P + \rho g h = P_o = \text{constant sufficient long enough and laminar flow}, \tag{5}$$

where:

ρ=density of the mud,

g=earth's gravitational acceleration,

h=vertical depth, and

P=pressure.

Additionally, P_0 can be determined for V=0 and h=0, for example.

Since the cross sectional area of the annulus **34** is needed to determine when a washout **54** has occurred, the equations are manipulated and solved for the area of the annulus **34** at a depth of h.

$$A_h = \left[\frac{\rho \dot{V}_{ref}}{2(P_0 - P_h + \rho g h)}\right]$$

where,

h, g and ρ are determined and known,

A_h=cross sectional area at depth h,

$\dot{V}_{ref}$=constant reference flow determined by the mud pump **50**, and

P_h=pressure at depth h

Thus, the cross sectional area of the annulus **34** at a given depth is a function of the flow rate and the pressure measured at that depth. These formulae are most accurate for idealized conditions that are assumed to be held true during measurements; mud flow is constant, mud density is constant, flow in the annulus **34** is laminar and the mud is incompressible. More sophisticated models may describe the physical behavior even better as disclosed below. As such, the washout detection system **10** monitors pressure at the pressure sensors **14** and calculates a corresponding annular area at the depths of each of the pressure sensors **14**. In response to the detection system **10** calculating an area greater than a selected value, the washout detection system **10** issues may sound an alert indicating that the washout **54** has occurred.

In alternate embodiments numerical models of the physical parameters could be used to derive a functional relationship between the pressure, P_h, at the downhole location and the area, A_h, of the annulus **34**.

Referring to FIG. **2**, another embodiment of a downhole drillstring washout detection system **110** disclosed herein is illustrated. Wherein the detection system **10** was directed at detecting washouts in the walls of a wellbore or a wellbore lining, the detection system **110** is directed to detecting a washout in the wall of a portion of the drillstring **18** itself such as a section of pipe, for example characterized by a hole therethrough through which flow can escape. The washout detection system **110** includes, a plurality of sensors **114** positioned along a drillstring **18**, a communication medium **22** coupled to the plurality of sensors **114**, and a processor **26** that is also coupled to the communication medium **22**. The communication medium **22** provides operable communication between the sensors **114** and the processor **26** and can include a wired pipe **28**, for example, which permits high bandwidth data transmission therethrough. As such, the processor **26** can be located at surface, as disclosed herein or at some other location along the drillstring **18**, such as in a bottom hole assembly **30**, for example, while monitoring the sensors **114**.

In this embodiment, four of the sensors **114** are located at points A, B, C and D. Point A is inside the drillstring **18** at a depth h_A, which may be at surface level, point B is outside the drillstring **18** at a depth h_B, which may be at surface level, point C is inside the drillstring **18** at a depth h_C, while point D is outside the drillstring **18** at a depth h_D. Note, although illustrated herein points C and D are at the same depth, alternate embodiment may have points C and D at different depths. The sensors **114** can be pressure sensors or flow sensors. An embodiment wherein the sensors **114** are pressure sensors will be discussed first.

In normal operation of a well the flow of mud from the mud pump **50** is down through the inside of the drillstring **18**, through the bit **32** and up through the annulus **34** and back to the surface. For a well without mud losses or fluid or gas influx the volumetric flow rate, $\dot{V}_{in}$, into the well is equal to the volumetric flow rate, $\dot{V}_{out}$, out of the well. The flow areas can be assumed known well enough and locally constant. According to Bernoulli's Equation:

$$P = P_0 - \rho g h - \frac{1}{2}\rho V^2 = P_o - \rho g h - \frac{1}{2}\rho\left[\frac{\dot{V}}{A_h}\right]^2 \qquad 7$$

Pressure, therefore, with $\dot{V}$=constant (long enough), A=constant, Rho=locally constant and g=constant for the well location, will only vary with depth h. Since depth is known, the change in pressure resulting from the depth is known as well.

By monitoring the pressures at different depths a washout **118** in the drillstring **18** can be detected. For example, the washout **118** in FIG. **2** allows mud to flow from inside the drillstring **18** to outside the drillstring **18** at a depth below points A and B but above points C and D. As such, the pressure at these four points will vary from the initial pressures, P_0, as follows:

$$P_A = P_{A_0},\ P_B \approx P_{B_0},\ P_C < P_{C_0},\ P_D < P_{D_0} \qquad 8$$

with P_A held constant by the mud pumps.

The processor **26** can, therefore, through observation of a change in pressure sensed by one of the sensors **114**, detect that a washout **118** has occurred. The processor **26** can issue an alert in response to detection of the washout **118** so that an operator may initiate a response. Additionally, a magnitude of the washout **118** will be related to the change in pressure encountered and, as such, a magnitude of the washout **118** can be approximated therefrom. The depth at which the washout **118** occurred can be determined by the location of the one or more sensors **14** for which the pressure readings have changed. Having more sensors **14** with closer spacing therebetween will increase the resolution through which the washout **118** is located.

In an alternate embodiment the washout detection system **110** can employ sensors **114** that are flow sensors instead of pressure sensors. The flow sensors **114** in this embodiment measure volumetric mud flow directly, $\dot{V}$. As such, a redirection of flow, for example, through the washout **118** in a wall of the drillstring **18**, will be detectable by the flow sensors **114** positioned below the washout **118** due to changes in flows sensed thereby. In contrast, flow sensors **114** above the washout will not sense a change in flow. Thus:

$$\dot{V}_A = \dot{V}_{A_0},\ \dot{V}_B = \dot{V}_{B_0},\ \dot{V}_C < \dot{V}_{C_0},\ \dot{V}_D < \dot{V}D_0 \qquad 9$$

With such information the processor **26**, by knowing the locations of the flow sensors **114** along the drillstring **18**, can determine a location of the washout **118** along the drillstring **18**. Additionally, by calculating a change in the flow rate sensed the processor **26** can determine the flow rate through the washout **118** and thus the severity of the washout **118**.

While the invention has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the claims.

What is claimed is:

1. A method of detecting a downhole washout, comprising:

positioning a plurality of sensors along a downhole drillstring;

communicatively coupling the plurality of sensors to a processor; and

analyzing data sensed by the plurality of sensors with the processor for relationships indicative of a washout including calculating a flow area with the data sensed.

2. The method of detecting a downhole washout of claim **1**, wherein the communicatively coupling includes connecting the plurality of sensors with wired pipe.

3. The method of detecting a downhole washout of claim **1**, further including assuming density of fluid sensed with the plurality of sensors is constant.

4. The method of detecting a downhole washout of claim **1**, further comprising assuming volumetric flow rates of fluid sensed with the plurality of sensors are constant.

5. The method of detecting a downhole washout of claim **1**, further comprising assuming that fluid sensed with the plurality of sensors is incompressible.

6. The method of detecting a downhole washout of claim **1**, further comprising assuming that fluid sensed by the plurality of sensors is mud.

7. The method of detecting a downhole washout of claim **1**, further comprising issuing an alert that the washout had occurred.

8. The method of detecting a downhole washout of claim **1**, wherein positioning a plurality sensors includes positioning a plurality of pressure sensors.

9. The method of detecting a downhole washout of claim **1**, further comprising assuming that flow through the flow area is a combination of laminar and turbulent.

10. The method of detecting a downhole washout of claim l, wherein the calculating includes calculating an annular flow area between the drillstring and a wellbore.

11. The method of detecting a downhole washout of claim **10**, further comprising assuming that flow through the annular flow area is laminar.

12. The method of detecting a downhole washout of claim **10**, further comprising assuming that flow through the annular flow area is turbulent.

13. The method of detecting a downhole washout of claim **1**, wherein the positioning the plurality of sensors includes positioning a plurality of flow sensors.

14. The method of detecting a downhole washout of claim **1**, further comprising determining the washout is a hole through the drillstring.

15. The method of detecting a downhole washout of claim **14**, further comprising calculating a flow rate through the washout.

16. A method of detecting a downhole washout, comprising:

positioning a plurality of sensors along a downhole drillstring;

communicatively coupling the plurality of sensors to a processor;

analyzing data sensed by the plurality of sensors with the processor for relationships indicative of a washout; and

calculating changes in flow area based upon changes in pressure measured with the plurality of pressure sensors.

17. A method of detecting a downhole washout, comprising:

positioning a plurality of sensors along a downhole drillstring;

communicatively coupling the plurality of sensors to a processor;

analyzing data sensed by the plurality of sensors with the processor for relationships indicative of a washout; and

locating the washout based upon data sensed by the plurality of sensors.

18. The downhole drillstring washout detection system of claim **17**, wherein the plurality of sensors are configured to sense a parameter inside of the drilistring.

19. The method of detecting a downhole washout of claim **17**, wherein the communicatively coupling includes connecting the plurality of sensors with wired pipe.

20. The method of detecting a downhole washout of claim **17**, further comprising issuing an alert that a washout had occurred.

21. The method of detecting a downhole washout of claim **17**, wherein positioning a plurality sensors includes positioning a plurality of pressure sensors.

* * * * *